Habitat Modeling and Preferences of Marine Mammals as a Function of Oceanographic Characteristics; Development of Predictive Tools for Assessing the Risks and the Impacts Due to Sound Emissions

Dr. Arianna Azzellino
Piazza Leonardo da Vinci, 32, 20133 Milano, Italy.
phone: (+39) 02-239-964-31 fax: (+39) 02-239-964-99 email: arianna.azzellino@polimi.it

Award Number: N000141010533

LONG-TERM GOALS

Long-term goals of this research are:

- Improving the knowledge about marine mammal ecology and about how ocean dynamics affect their distribution and behavior in different areas;
- Developing the tools enabling to predict marine mammal presence probability or density on the basis of the data available to detect their presence (i.e. visual observations or acoustic detections) and the available environmental predictors;
- Creating the knowledge-based background about potential mitigation measures appropriate for different areas;
- Creating a Decision Support System of Rules that will constitute a guideline for choosing the appropriate combination of the tools at managers' disposal which is likely to be the best way to maximize effective mitigation efforts.

OBJECTIVES

Three are the main scientific objectives of this research:

Objective 1) Development of methods to integrate acoustic and visual data in marine mammal distribution/density models;

Objective 2) Evaluation of the model transferability to areas different from the zone of calibration;

Objective 3) Definition of a knowledge-based decision support framework for managing the impact of the noise-producing human activities.

APPROACH

The graph in Figure 1 outlines the set of tasks composing the Objectives of the research for the development of the risk assessment models. The technical approach for every Objective is discussed in the following paragraphs.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2012**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Habitat Modeling and Preferences of Marine Mammals as a Function of Oceanographic Characteristics; Development of Predictive Tools for Assessing the Risks and the Impacts Due to Sound Emissions**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Piazza Leonardo da Vinci, 32, 20133 Milano, Italy.**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**16**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

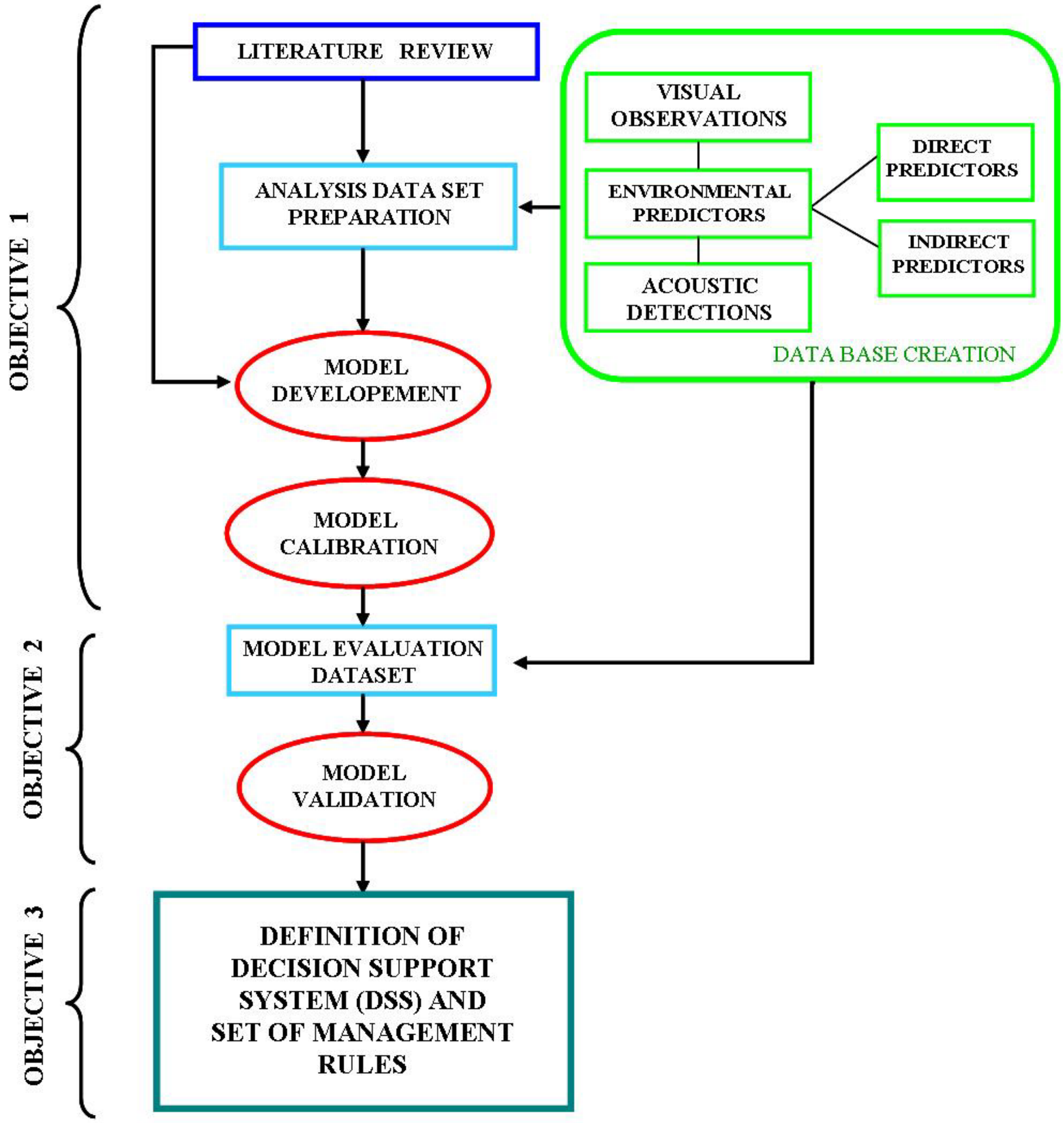


Figure 1. Risk Assessment Models Development Process.

Research tasks (boxes) included in every research Objective.: Literature review: critical review of different statistical methodology , response variables and predictors availability; Database creation: data acquiring of the sightings, passive acoustic detections and indirect (mainly physiographical parameters such as depth, slope)and direct (data from CTD probes such as temperature, salinity; data from remote sensing such as Chl-a) predictors; Analysis datasets: preparation of dataset for developing and running different model exercises (calibration/validation models); Modeling: calibration, best model selection, validation, scenario analysis; Decision Support System: guideline framework for choosing the appropriate set of risk mitigation alternatives.

Objective 1:
Modeling exercises will be run for determining regions of high and low marine mammal presence/density through the analysis of the literature available, the oceanographic, biological and historical information available on the Mediterranean and the Antarctic study area. Different statistical approaches (e.g. Logistic regressions, Generalized Linear Models) will be used to model density and presence/absence patterns of target species. A consolidate methodology will be developed to integrate acoustic and visual data in marine mammal distribution models.

Objective 2:
The transferability of the developed models to areas different from the zone of calibration, and the assessment of behavioral differences of the same species inhabiting different areas will be evaluate by using different environmental parameters such as indirect (depth, slope..) and direct (temperature, salinity..) ecological gradients. The analysis of model results of the same species in different areas (e.g. Ligurian sea, Alboran sea) allow to outline behavioral differences that may affect their distribution pattern and response to environmental predictors.

Objective 3:
The components of systems for managing the effects of sound on marine mammals include knowledge and research, risk assessment, permit and authorization processes, mitigation tools and monitoring, evaluation, enforcement, and compliance activities. Mitigation may consist of different alternatives that could be more or less appropriate from case to case. The choice among different mitigation alternatives designed to prevent, reduce or rectify the impacts of sound introduced into the marine environment may be guided through a set of rules, based on risk predictions, organized into a decisional framework which will also include the suite of tools needed to support decisions.

Key individuals of the research are:
Arianna Azzellino, PhD: Principal Investigator (PI)
Caterina Lanfredi: Phd student (PS)

Roles played by principal investigator (PI) and the PhD student (PS):

PS	Literature review
PI+PS	Data acquiring and database creation
PS	Analysis data set preparation
PI+PS	Modeling (calibration, best model selection, validation, scenario analysis)
PI+PS	DSS system creation when used in areas different from the calibration site.

WORK COMPLETED

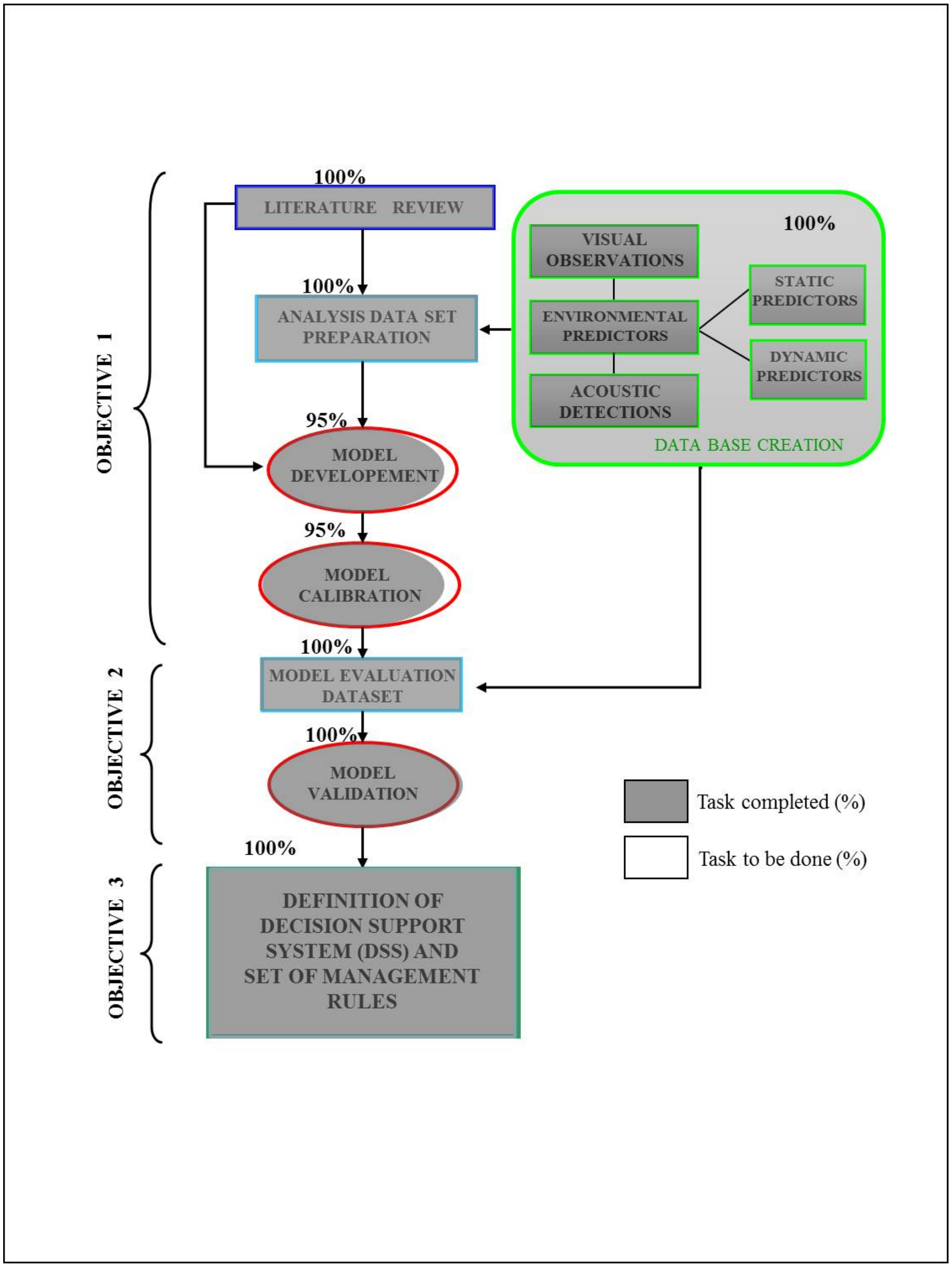


Figure 2. Risk Assessment Models Development Process

RESULTS

Objective 1: Model Development

Mediterranean Sea - Cetaceans modeling exercises were developed in high and low marine mammal presence/density areas by using both static and dynamic predictors of cetaceans habitat preference.

Logistic regressions approach was used to model presence/absence patterns of target species. Acoustic and visual data were integrated to study marine mammal distribution. Modeling exercises were run in different areas of the Mediterranean sea combining visual observations, passive acoustic detections and environmental predictors coming from research trials conducted in the Ligurian Sea (north-western Mediterranean Sea) Alboran Sea (Southwestern Mediterranean Sea) and Tyrrhenian Sea (Central Mediterranean Sea), (see Fig 3).

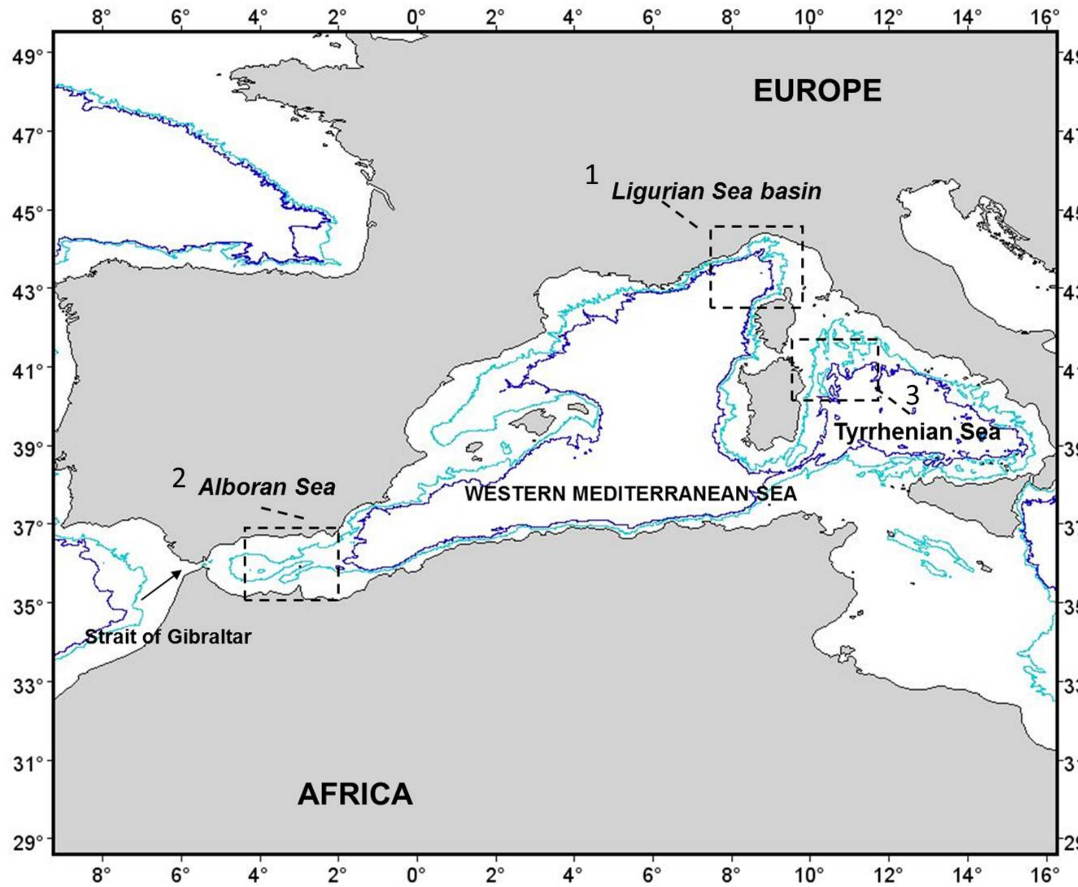


Figure 3. Mediterranean Sea study areas: 1. Northwestern Mediterranean Sea (Ligurian Sea Basin) and 2. Southwestern Mediterranean Sea (Alboran Sea) and 3. Central Mediterranean Sea (Tyrrhenian Sea). 1000 m (light blue lines) and 2000 m (blue lines) depth contours are shown.

Static Predictors - After reviewing the existing literature about habitat models, the logistic regression approach was identified as one of the most effective to analyze presence/absence data. Logistic modeling exercises were run in different areas of the Mediterranean sea, using visual observations data (Azzellino et al., 2011 and Azzellino et al., 2012; see Figure 4).

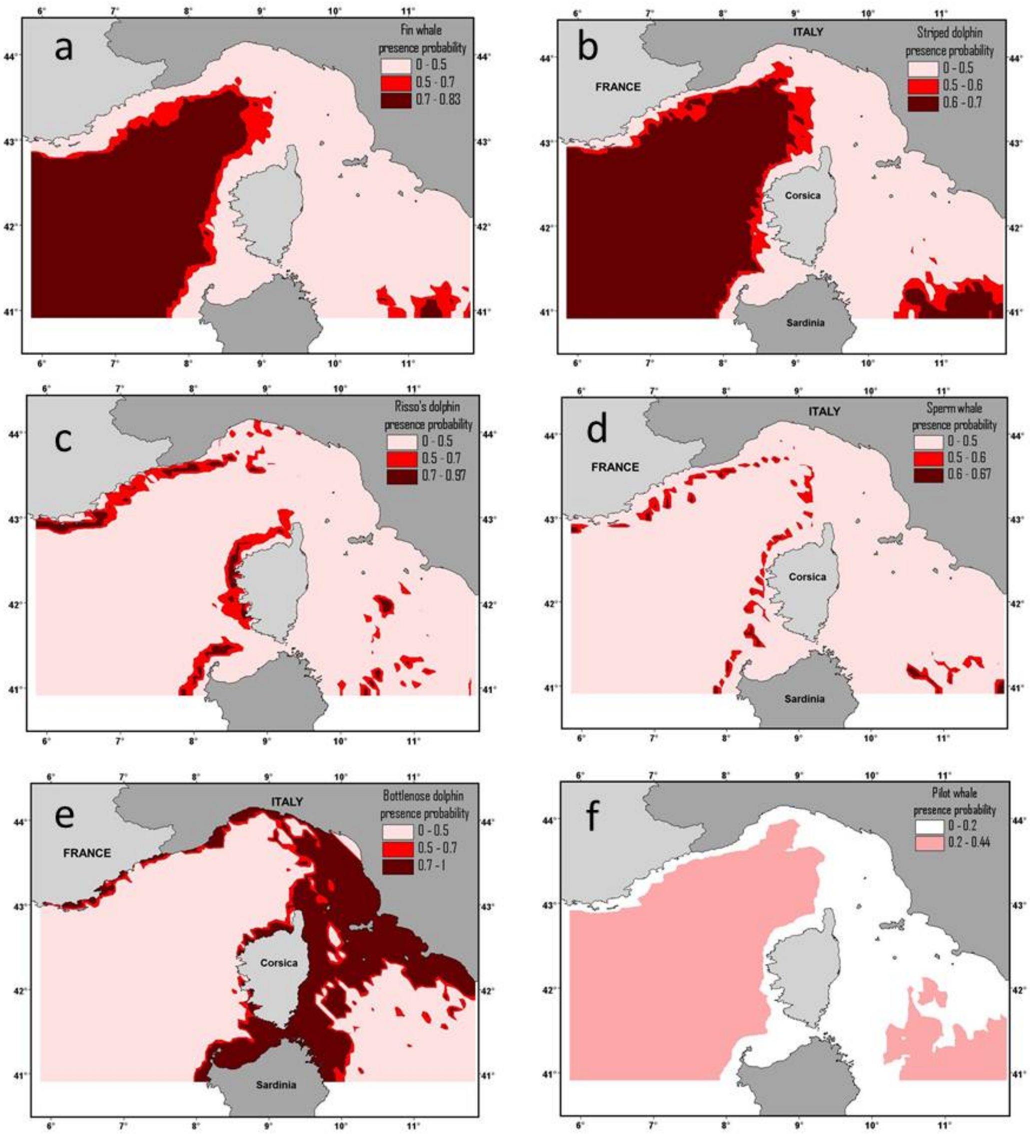


Fig.4. (a) Spatial prediction of fin whale relative presence probability. Higher probabilities of presence are indicated in red (more than 50%) and brown (more than 70%). (b) Spatial prediction of striped dolphin relative presence probability. Higher probabilities of presence are indicated in red (more than 50%) and brown (more than 60%). (c) Spatial prediction of Risso's dolphin relative presence probability. Higher probabilities of presence are indicated in red (more than 50%) and brown (more than 70%). (d) Spatial prediction of sperm whale relative presence probability. Higher probabilities of presence are indicated in red (more than 50%) and brown (more than 60%). (e) Spatial prediction of bottlenose dolphin relative presence probability. Higher probabilities of presence are indicated in red (more than 50%) and brown (more than 70%). (f) Spatial prediction of long-finned pilot whale relative presence probability. Higher probabilities of presence are indicated in light red (from 20% up to 44%).

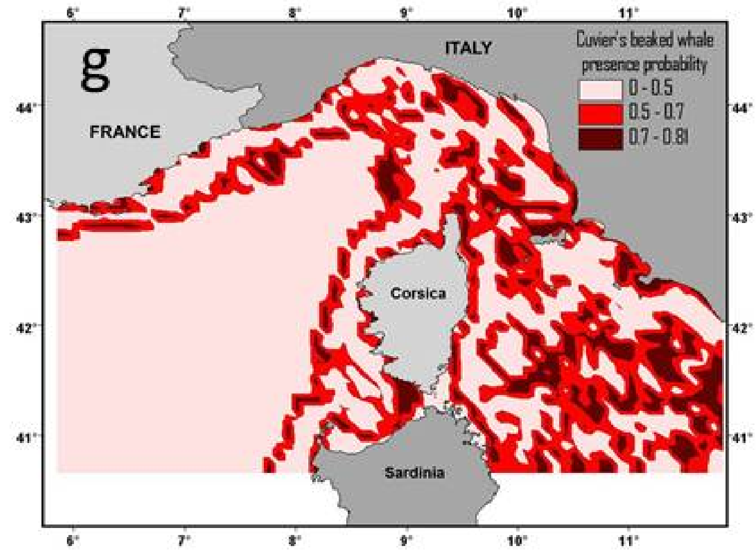
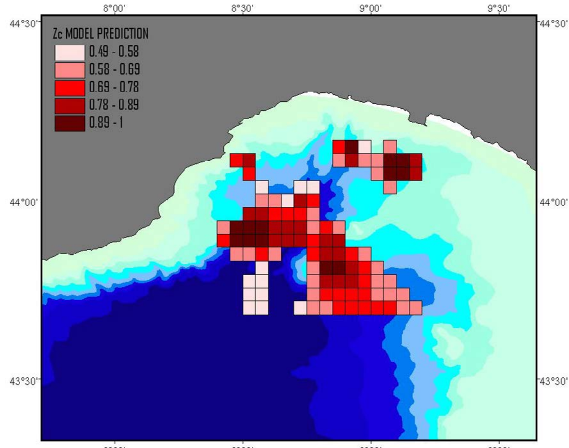


Figure. 4 (continued). (g) Spatial prediction of Cuvier's beaked whale relative presence probability. Higher probabilities of presence are indicated in red (more than 50%) and brown (more than 70%).

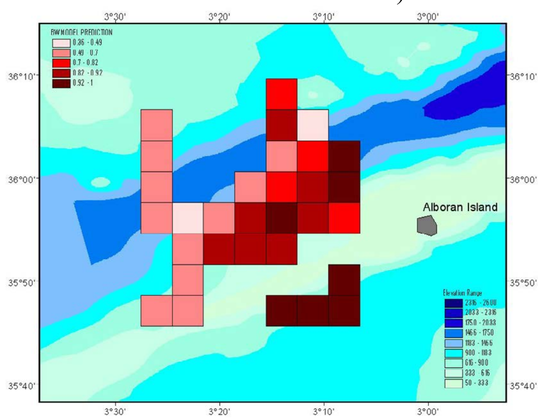
Dynamic Predictors - The correlation between marine mammals occurrence and oceanographic parameters was analyzed for three key areas of the Mediterranean Sea: the Genoa canyon area in the Ligurian Sea, the waters surrounding Alboran island in the Alboran Sea, and the Northwestern Tyrrhenian Sea (Fig.1). Target species of this exercises was the Cuvier's beaked whale (*Ziphius cavirostris*). Visual observations, acoustic detections and concurrent oceanographic data were analyzed in each of these areas respectively. Oceanographic measurement were taken as a function of depth from surface to 1000 m of depth, using sensors installed on a Conductivity, Temperature, Depth (CTD) Rosette Frame deployed from the NATO R/V Alliance at predefined stations In the CTD stations the following oceanographic data were collected: conductivity (mS/cm), to determine salinity, temperature (°C), pressure to determine depth at which measurements are taken , fluorescence (ug/l) as a proxy for chlorophyll a, dissolved oxygen (ml/l), turbidity (FTU) and finally sound velocity (m/s) derived from salinity and temperature measurements. 39 water column statistics were computed for every oceanographic parameter collected in every station. These statistic were used as covariates in the model. Details of dataset considered for the analysis is presented in Table 1. Stepwise Logistic Regression analysis was performed by using the water column statistic as covariates. In all the study areas, the species presence was found significantly ($P < 0.05$) correlated with features of the dissolved oxygen profiles in particular with the depth (m) of maximum values of the dissolved oxygen (ml/l) (*Depth* O_2 *max*). All the models had a good overall accuracy, around 70% (Fig.5).

Table1. Analysis database used for the modeling exercises.

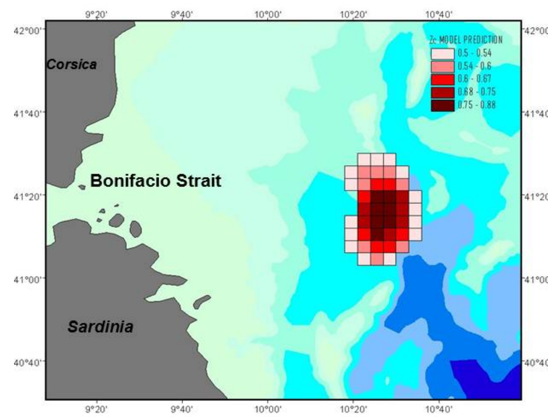
Areas	Ligurian Sea	Alboran Sea	Tyrrhenian Sea
Research Trials	*Sirena '02*	*Sirena '08*	*Med '09*
Time period	*5 - 23 July*	*17 May - 18 June*	*29 August - 4 September*
Research Vessel	*NRV Alliance*	*NRV Alliance*	*NRV Alliance*
CTD stations	*21*	*31*	*5*
BW sightings	*24*	*6*	*6*
BW acoustic detections		*5*	*9*



a)



b)



c)

Figure 5. Beaked whale presence probability predictions based on the use of depth of maximum values of the dissolved oxygen (Depth O_2 Max) as predictor. a) Ligurian Sea, Genoa canyon area b) Alboran Sea, Alboran Island area and c) Northwestern Tyrrhenian Sea. Higher probabilities of presence are indicated in red (more than 50%) and brown (more than 70%).

Inverse correlations were outlined in the Alboran Island area and Northwestern Tyrrhenian area while a direct correlation occurred in the Ligurian Sea area (Fig. 6). These correlations suggest that the depth of the maximum dissolved oxygen may be a proxy of water masses exchanges in different areas of the Mediterranean. The direct or inverse correlation with this parameter may be in fact explained by the dynamic of such water masses exchanges (downwelling or upwelling phenomena). While both Alboran site and Tyrrhenian site are characterized by upwelling phenomena respectively topography- and wind-induced, the Genoa canyon area is characterized by a topography-induced downwelling. Marine environments with highly hydrodynamic (e.g. with gyre presence) are suggested to be areas of special ecological meaning for beaked whales. Details of this analysis were presented in a conference paper (see Lanfredi et al., 2011), while a full paper is about to be submitted to PloSOne.

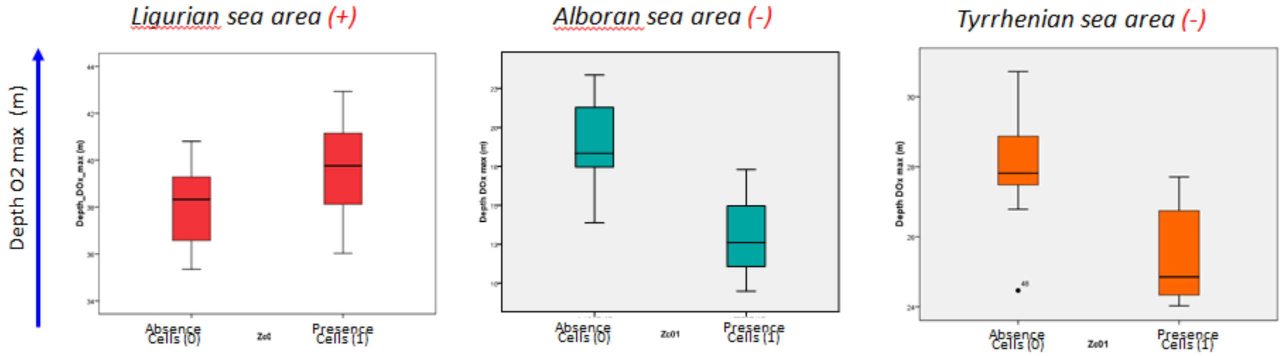


Figure 6. Comparison between the beaked whale presence/ absence cells depth O_2 max values in the three study areas.

Antarctic Peninsula (Southern Ocean) - From 13 March to 09 April 2012 a German fishery research expedition was conducted an board the AWI (Alfred Wegener Institute for Polar and Marine research) research icebreaker " Polarstern" in the Scotia Sea (Elephant Island - South Shetland Island - Joinville Island area) under the auspices of CCAMLR. During this expedition, ANT-XXVIII/4, an opportunistic marine mammal survey was carried out. Concurrently oceanographic data were collected as a function of depth using sensors installed on a Conductivity, Temperature, Depth (CTD) Rosette Frame, deployed from the RV Polarstern. Data were collected for 26 days along the externally preset cruise track, resulting in 295 hrs on effort. Within the study area 248 sightings were collected (Table 2, Fig.7), including three different species of baleen whales, fin whale (*Balaenoptera physalus),* humpback whale (*Megaptera novaeangliae*), and Antarctic minke whale (*Balaenoptera bonaerensis*) and one toothed whale species, killer whale (*Orcinus orca*). More than 62% of the sightings recorded were fin whales (155 sightings) which were mainly related to the Elephant Island area (116 sightings). Large pods of fin whales were observed feeding in shallow waters (< 300 m) on the north-western shelf off Elephant Island, correlated with large aggregations of Antarctic krill (*Euphausia superba*). Model calibration and develpment is still ongoing on this dataset. Both static and dynamic predictors (e.g. bathymetry, remote sensing data, CTD and prey biomass) are considered. A first communication paper was sent to the IWC (see Burkhardt and Lanfredi, 2012) where Elephant Island is suggested being an important feeding area for fin whales in the early austral fall.

Table 2. List of cetacean sightings collected during ANTXXVIII/4 (EI= Elephant Island, SSI= South Shetland Island and JI= Joinville Island)

Species	**Study Areas**			**Total**
	EI	**JI**	**SSI**	
Fin whale	*116*	*4*	*35*	*155*
Humpback whale	*1*	*6*	*1*	*8*
Antarctic minke whale	*0*	*2*	*0*	*2*
Killer whale	*0*	*1*	*0*	*1*
undefined large whale	*57*	*2*	*16*	*75*
undefined small whale	*1*	*0*	*0*	*1*
undefined whale	*2*	*4*	*0*	*6*
Total	***177***	***19***	***52***	***248***

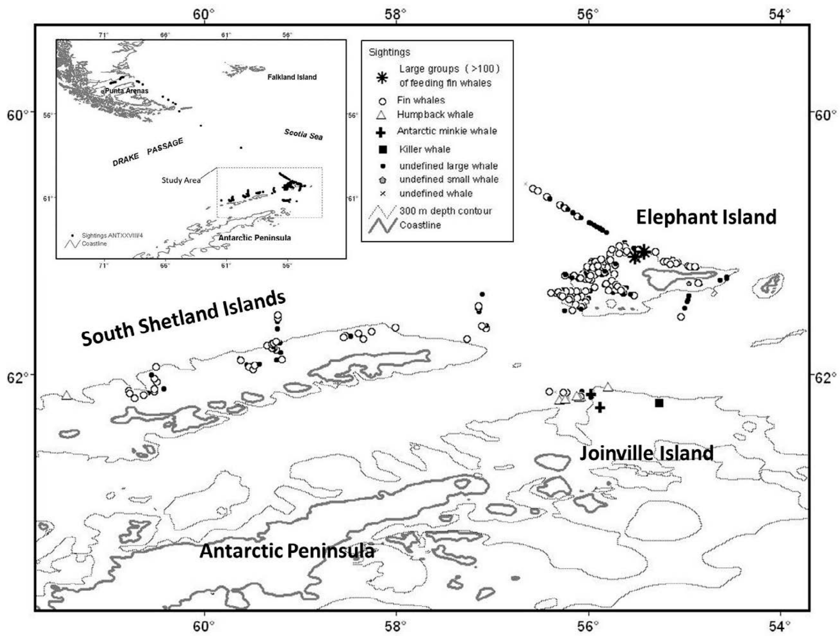


Figure 7. Map of cetacean sightings collected in the primary study area (South Shetland Island – Elephant Island - Joinville Island) during RV Polarstern expedition ANT-XXVIII/4. Sightings collected throughout the entire expedition are shown in the top left insert.

Acoustic and Visual Based Models - Target species of this modelling exercises were the Cuvier's beaked whale (*Ziphius cavirostris*), the sperm whale (*Physeter macrocephalus*) and dolphins (genus *Delphinidae).* In this study, the visual and acoustic data collected during the third leg of the research expediton MED-09 in the Tyrrhenian Sea area were modeled (Table 3). The correlations between cetacean occurrence and physiographic parameters (i.e depth and slope) were investigated with the aim of comparing the results obtained from modeling acoustic-based and visual-based presence/absence data.

Table 3. Visual and Acoustic data set used for the modeling exercises.

Med 09 (leg 3) Data	Beaked whale	Sperm whale	Dolphins	Fin whale
# of sightings	*6*	*18*	*57*	*22*
# of acustic detections	*8*	*21*	*58*	

A Stepwise logistic regression approach was used to predict both the visual observations and the acoustic detections. The cell statistics of depth and slope were used as covariates. Significant correlations were outlined ($P < 0.05$) for all the species either using visual or acoustic data. All the models showed good fit, however visual-based models had higher accuracies, 60% to 89% vs 51% to 63% of correct overall classifications (Fig.8). This model exercise demonstrated that acoustic data can be used for modeling cetacean presence/absence although further work should be done to understand how to improve the accuracy of the acoustic-based models. (See details in Podestà et al., 2011)

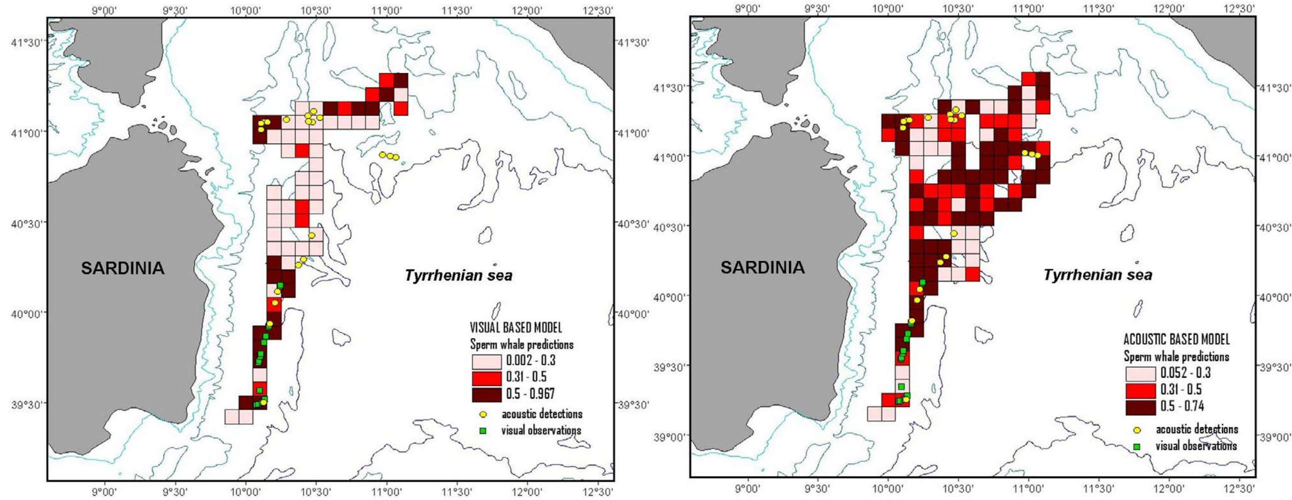


Fig. 8. Sperm whale Visual-based (left) and Acoustic-based (right) presence probability predictions. Sperm whale sightings (green squares) and acoustic detections (yellow circles) are also shown.

OBJECTIVE 2: Model transferability

Cuvier's beaked whale was chosen as target species. The Ligurian sea area dataset was chosen for model calibration, whereas the Alboran sea dataset was used to validate the Ligurian sea models. Details of the analysis datasets considered are presented in Table 4. Topographical predictors, such as depth and seabed slope, were used as covariates within the regression models. Also remote sensed chlorophyll-a concentrations, obtained from the SeaWiFS 8 day data products, generated by the NASA Ocean Biology Processing Group (http://disc.sci.gsfc.nasa.gov/giovanni/) were used as predictors. Details of this analysis can be found in Azzellino et al., 2011.

Table 4. Analysis database used for the modeling exercise. Transferability to Alboran area (validation site) of the developed model in the Ligurian area (calibration site) was tested.

	LIGURIAN SEA			ALBORAN SEA
NURC Trias	**Sirena 01**	**Sirena 02**	**Sirena 03**	**Sirena 08**
Time Period	*17-Sep 7-Oct*	*5 - 23 July*	*25-Aug 12-Sep*	*17 May - June 18*
Research Vessels	*NRV Alliance ITS A. Magnagni T-boat Manning*	*NRV Alliance*	*NRV Alliance ITS A. Magnagni CRV Leonardo RV Urania*	*NRV Alliance*
Positve Effort * (km)	*2339.39*	*1700.54*	*3401.03*	*504*
BW sightings	*0*	*24*	*2*	*16*
BW cluster of acoustic detections	*/*	*/*	*/*	*59*
Tot. Sighting	*141*	*225*	*179*	*316*

* Km conducted with 4 visual observer and Beaufort sea state < 4

Model Calibration - The classification performances of the models developed in the Ligurian Sea have been evaluated either using the chlorophyll (i.e. dynamic predictors) or the topographical features (i.e. static predictors) as predictors. The accuracy was found slightly lower for the models using the dynamic predictors rather than static predictors (i.e. 73% vs 87%). Besides the differences in accuracy, the two models showed a very good agreement in their predictions (Fig. 9).

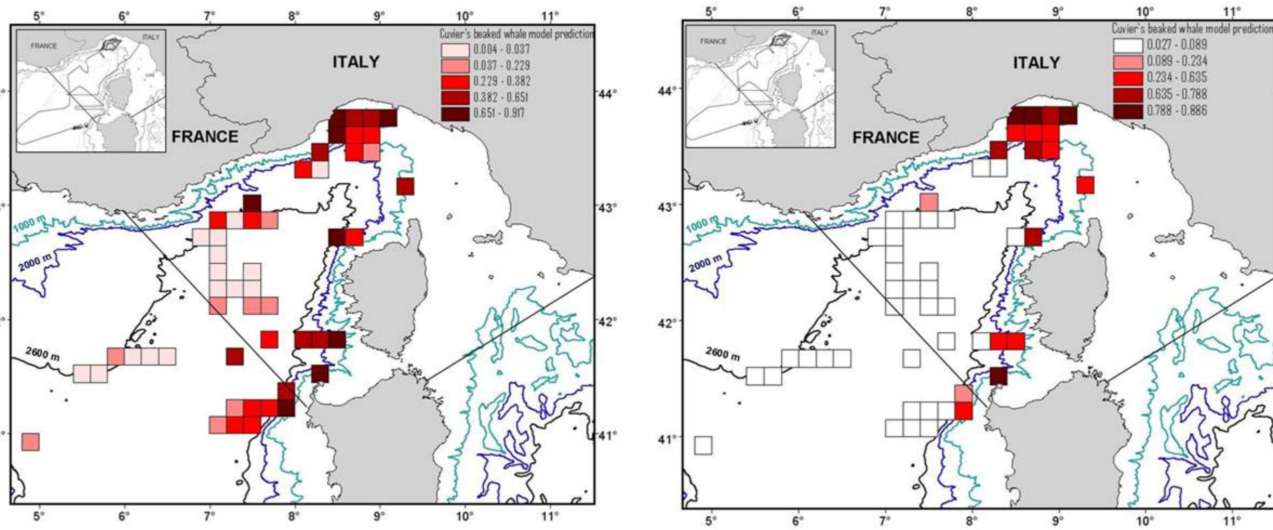


Fig. 9. Beaked whale presence probability predictions for Ligurian Sea Basin according to the bathymetry model (left) and chlorophyll model (right). The "Pelagos Sanctuary" borders are also shown.

Model Validation - By using the same predictors selected for the Ligurian Sea *a priori* prediction map of presence and absence cells was produced for the Alboran Sea area. These predictions were overlaid with the Cuvier's beaked whale observations collected during the Sirena 08 cruise (Fig 10). The accuracy of the a priori predictions were evaluated through the analysis of sensitivity and specificity. Moreover, to increase the validation data set, the visual observations, strongly affected by unfavorable weather conditions, were integrated with acoustic detections. A significant finding of this first model exercise was the evidence that, although the models showed approximately the same accuracy for presence predictions, the accuracy for absence predictions was found to be inversely correlated to the overall accuracy evaluated in the calibration phase. Also, it is worthwhile to point out that the model predictions, either based on bathymetry or chlorophyll features, were surprisingly comparable in both the study areas. It could be questioned that both bathymetry and chlorophyll are indirect predictors for beaked whales and how the observed patterns could be interpreted ecologically. Probably these features can be seen as proxies of the macro-scale features that indirectly outline beaked whale habitats. It is true that these proxies may not apply for different species, however, as far as beaked whales are concerned and as far as the macro-scale features involved in different study areas may be considered comparable, we believe these results as encouraging and supporting the idea that modeling tools can be employed for the preliminary risk assessment of "unsurveyed" areas.

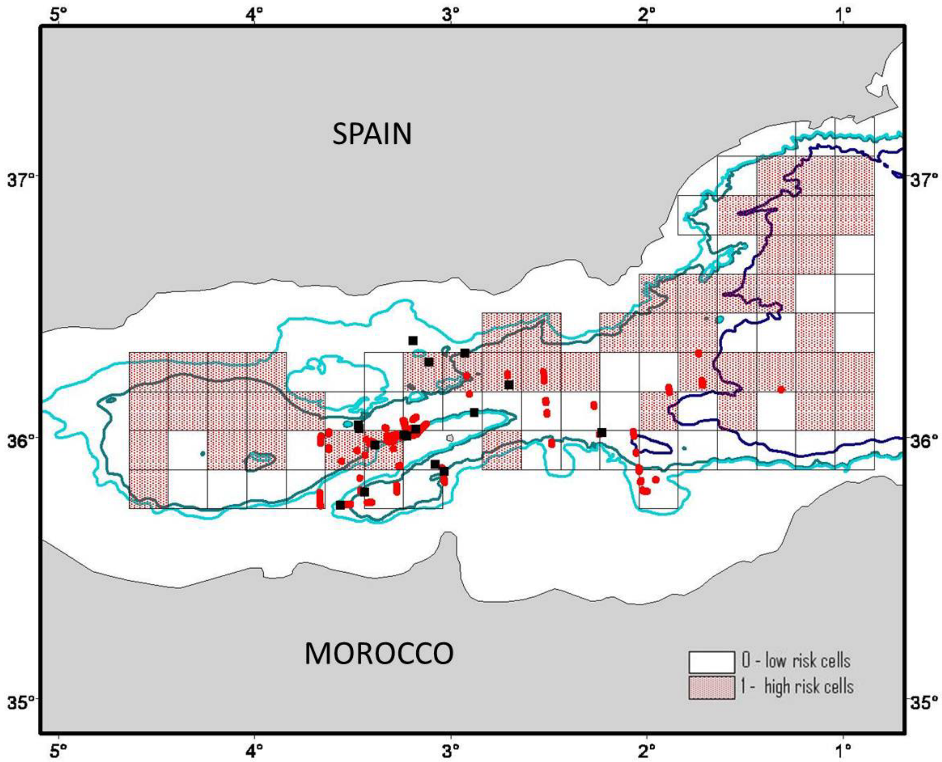


Fig. 10. A priori prediction for the Alboran Sea area: high risk (i.e. presence probability higher than 75%) and low risk (i.e. presence probability lower than 75%) cells are shown in colours. Beaked whale observations are also shown as dark full squares whereas clusters of acoustic detections are shown as gray full circles.

OBJECTIVE 3: Knowledge-based decision support framework

The choice among different management alternatives to prevent, reduce or rectify the impacts of sound introduced into the marine environment may be guided through a set of rules, based on risk predictions, organized into a decisional framework which will also include the suite of tools needed to support decisions. The ability to model the species presence may lead to the conservative avoidance of areas predicted as high risk. Predictive models, either based on visual observations or on acoustic detections may be used to evaluate the possible exposure to specific sound sources in different regions.

Lower accuracy predictions, as the ones that can be obtained by a model calibrated in a different area or by a model based on acoustic detections, may be employed for the preliminary risk assessment of ‘‘unsurveyed’’ areas, but they should be managed very carefully. The application of uncertainty buffers (e.g. see Fig. 11) may guarantee that the prediction process is appropriately conservative.

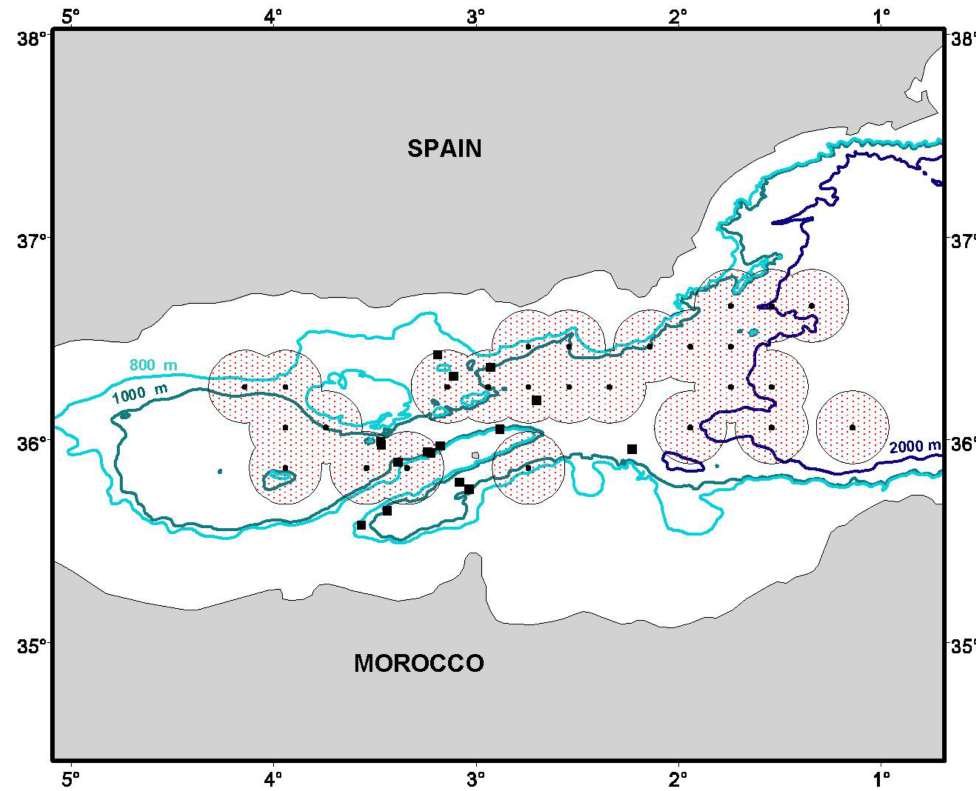


Fig. 11. Risk prediction map for the Alboran Sea area based on a 20 km buffer applied to the high risk cell centroids. Beaked whale observations are also shown as dark full squares.

Moreover, the increasing awareness of the cumulative effects of human activities on the marine environments has led to an increased requirement for Marine Spatial Planning (MSP) to fulfil the need to take a holistic and integrated approach to management. Therefore the impacts of the development of new activities must be considered in the context of the existing pressures and of their uncertainties. Spatial decision support systems, using environmental and social data and models may contribute to the efficient exchange of information between experts, stakeholders and decision makers. Scenario analysis through the prediction of the areas of potential conflicts, may offer the opportunity for early negotiations between stakeholders and to the impact mitigations. The environmental background need to be considered through set of multiple indicators (e.g. pollution risk, marine biodiversity, presence of vulnerable species, climate induced changes etc.). The environmental indicators need to be aggregated into impact indexes that will constitute the basis for evaluating the sostainability of a certain set of human pressures. Multivariate analysis techniques may allow to disentangle the different components of the environmental vulnerability (e.g. Azzellino et al., 2011b) and may support management decisions. Special emphasis should be given to multicriteria analysis approaches to the environmental impact considerations. A spatial planning framework would have the potential to guide the transition from the single sector management toward the integrated management of sea uses. Figure 12 shows the scheme of a suitable knowledge-based decisional support framework.

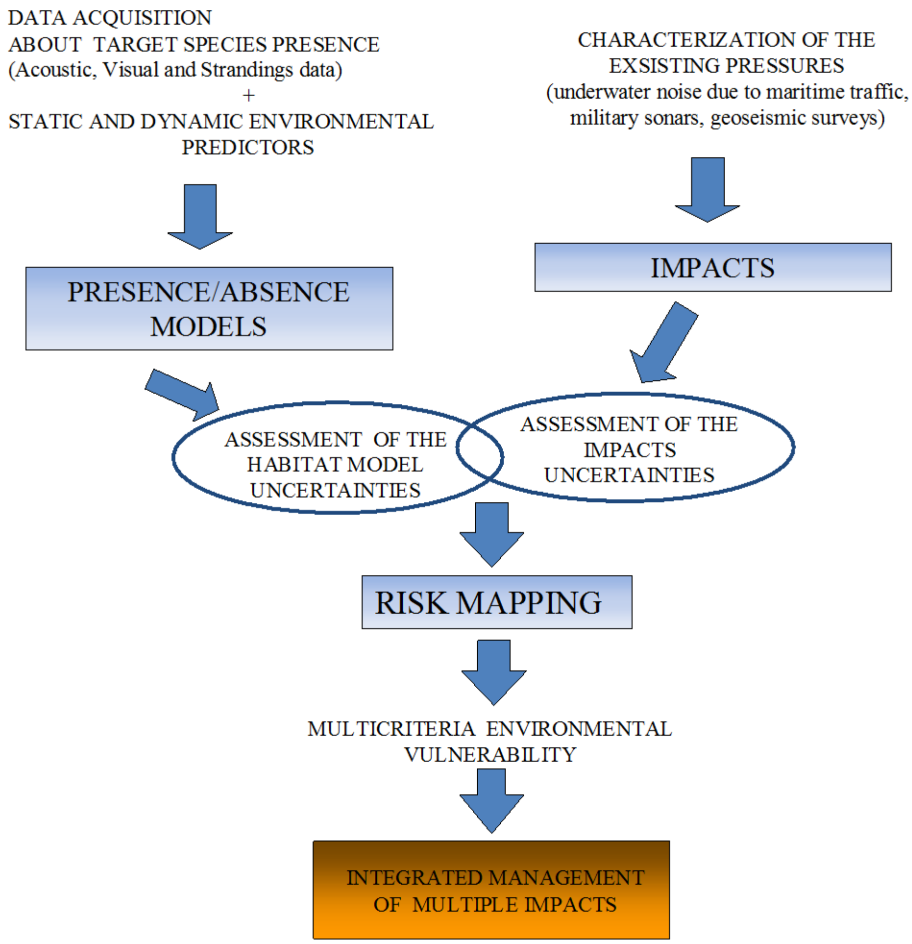


Figure 12. scheme of a knowledge-based decision support framework.

Such a framework may help sound-producers and managers of the environment in choosing between mitigations alternatives. An example of the framework application is given in Azzellino et al., 2011b where the optimal siting of a new underwater-noise-producing facility, a wave-energy conversion farm is provided through a multicriteria analysis approach.

IMPACT/APPLICATIONS

Understanding of marine mammals habitat preferences represent a critical step forward the developing of Risk Assessment tools that may help managers and sound-producers in predicting which areas support high densities and should deserve a higher protection level. Once determined the key habitat characteristics and developed the tools to estimate the probabilities of high or low density areas, it is possible to manage the estimated risks through proposing mitigations measures. This research contributed in creating the risk based background about potential mitigation measures appropriate for different study areas allowing sound-producers in choosing between the best set of mitigations alternatives.

RELATED PROJECTS

The project entiteled “Marine Mammal Risk Mitigation Projects” cunducted by NATO Undersea Research Centre (NURC) in La Spezia, Italy (http://www.nurc.nato.int/research/mmrm.htm), is closly related to this reaseach. To study the distribution of mammals we are using an multiyear, integrated dataset based on oceanographic, biologic, and hydrographic parameters. The analysis dataset include the NURC/MMRM database of marine mammals sighting, oceanographic parameters (CTD, XBT, XCTD) and passive acoustic detections and sound samples provided for NURC by CIBRA, Centro Interdisciplinare di Bioacustica Ricerche Ambientali University of Pavia(http://www3.unipv.it/cibra/).

PUBLICATIONS

Azzellino A., Panigada S., Lanfredi C., Zanardelli M., Airoldi, S. and Notarbartolo di Sciara, G. 2012. Predictive habitat models for managing marine areas: spatial and temporal distribution of marine mammals within the Pelagos Sanctuary (northwestern Mediterranean Sea). Ocean and Costal Management, 67:63-74.

Azzellino, A., Lanfredi, C., D’Amico, A., Pavan, G., Podestà, M., Haun, J. 2011a Risk mapping for sensitive species to underwater anthropogenic sound emissions: model development and validation in two Mediterranean areas Marine Pollution Bulletin, 63: 56- 70.

Burkhardt, E. and Lanfredi C.**.** 2012: Fall feeding aggregations of fin whales off Elephant Island (Antarctica). IWC paper SC/64/SH9

International Conference Proceedings:

Lanfredi, C., Azzellino, A., D’Amico, A., Ampolo Rella, M., Podestà, M., Pavan, G., Francia, C. 2011. Does dissolved oxygen play a role in Cuvier’s beaked whale habitat selection? A comparison between three study areas in the western Mediterranean Sea. In Proceedings of 25th Annual Conference of the European Cetacean Society. Cadiz , Spain , 21-23 March 2011

Podestà M. , Lanfredi C. , Azzellino, A. , D’Amico A. , Pavan G. , Francia, C. Comparison between visual-based and acoustic-based distribution models to predict cetaceans presence in the Northwestern Tyrrhenian Sea. Proceedings of 25th Annual Conference of the European Cetacean Society. Cadiz, Spain , 21-23 March 2011

Azzellino , P. Contestabile, V. Ferrante, Lanfredi C., D. Vicinanza. 2011b. Strategic Environmental Assessment to evaluate WEC projects in the perspective of the environmental cost-benefit analysis. Proceedings of the Twienty first- ISOPE Conference. International Society of Offshore and Polar Engineering ISBN 978-1-880653-96-8 (Set) 584-589